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A Study on Prediction of the Optimal Process Parameters for GMA Root-pass welding in Pipeline

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Abstract

Conventionally, welding processes are highly labor-intensive and need skilled operators. Compared to plate welding process, pipe welding process imposes higher skill requirement on operators and sound welds which guaranteed to be repeatable from weld to weld because of the harsh environment and intense process disturbance. Also, the automated arc welding process becomes important for productivity, quality and cost-efficiency. Even if many welding parameters, such as the arc current, welding voltage and weld speed, can affect the result of weldability, most of the automated welding system cannot handle so many welding parameters online to adapt the change of conditions during the weld process. Therefore, a suitable control algorithm to get a good weld quality in the pipe welding process must be developed
The objective of this study is focused on developing an automatic control algorithm not only to improve the productivity, quality and efficiency of the STT (Surface Tension Transfer) welding process, but also to select the optimal welding conditions for root-pass welding. This algorithm should be able to adjust the optimal welding parameters to ensure the welding quality and overcome the process variability, fluctuation and disturbance.

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Keywords: Pipe welding, Root-pass welding, STT(Surface Tension Transfer), Vertical welding, Overhead welding

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1. Introduction

The welding technology, a core technology in the manufacturing industry, is a representing 3D field which the workers are not willing to perform due to poor working environment and large physical burden. Recently, the welding automation has been emerged as a major issue in the national competitiveness because of decreasing the number of experienced welding workers, aging and increasing the labor cost [1]. In particular, the marine shipbuilding industry is the field which requires the design, production, management technologies and cutting-edge IT technologies as well as shall require the technicians with the proper size due to the limitation in the automation of manufacturing large-sized structures and a very wide range of the shipbuilding process. Since there are a substantial number of pipes inside the vessel, the pipe welding process is a core part of manufacturing for the shipbuilding and marine structures and accounts for more than 50% of the total production process [2].

In particular, the welding process features low rate of automation and high technical difficulties. The circumferential welding for most pipes in Korea consists of the manual Gas Tungsten Arc(GTA) welding, and many studies have been performed to apply the circumferential automatic welding process [3~4]. The welding quality of the GTA welding process depends on the capability for the welding personnel and holds a lot of problems in developing the automation system due to very low reproducibility and repeatability. Even worse, the welding process may not lead the molten pool depending on the arrangement of the pipes with the open-gap, causing the burn through and difficulties in continuous welding due to the short-circuiting phenomena. To solve this problem, the Gas Metal Arc (GMA) welding is employed and applied to the root-pass welding of the pipe despite of the slightly falling accuracy.

The root-pass quality in the pipe may be represented by the back-bead geometry so that it is important to investigate the relationship between the welding conditions and the back-bead geometry for the welding automation. In addition, the welding process consists of multiple inputs and outputs so that the output parameters related to the bead geometry are correlated with each other. Various studies on the optimal welding conditions and the bead geometry have been performed, and many techniques are proposed to analyze the correlation between the input and the output variables and determine the optimized process parameters from the developed models [5]-[8]. Shinoda and Doherty [6] and Kim and Rhee [7] designed to the optimal fuzzy logic controller using the response surface methodology to indicate the correlation between the welding parameters and bead geometry to improve the welding quality in the bead geometry. Furthermore, root-pass weld in most welded pipe solely depends on the experience of workers in relation to guarantee a stable weld quality. However, the systematic correlation between these variables while selecting has not yet been identified..

The study is to investigate the effects of the welding parameters (torch angle and welding speed) on the back-bead geometry(back-bead width and back-bead height) in the vertical and overhead positions of pipe welding. The experimental results were employed to develop the mathematical model to the selection of optimal welding condition was proposed in the root-pass welding which was done along the V-grooved butt weld joint, and verity the significance in the developed model.

2. Experimental Works

2.1. Experimental Procedure

The experiment has been performed to optimize the welding parameters in the overhead and the vertical positions of pipe welding processes due to the one of most difficult parts in the automation for the open-gap pipes. To verify the effects of the welding speed and torch angle like Fig. 1, the experiment prepared the flat specimens for the welding as shown in Fig. 2. The experiment system was configured with the linear carriage, guide rail, STT welding machine and specimens fixed jig to control the welding speed. The carriage movement was controlled by the separated controller and the torch angle was manually controlled from the carriage device.

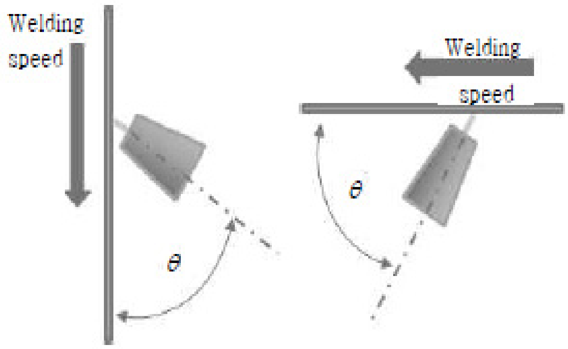

Fig. 1. Concept of welding experiment

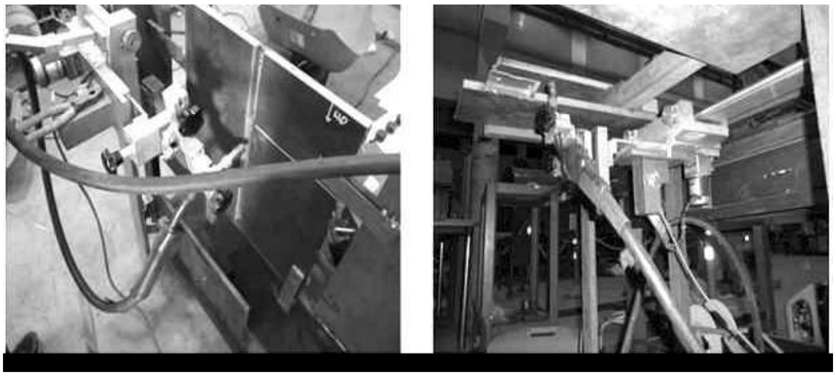

Fig. 2. Experimental welding system employed

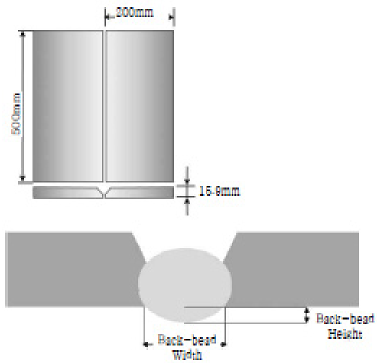

Fig. 3. Configuration of welding specimen

The shielding gas was 100% CO2 and the gas flow rate supplied to the torch was chosen 15 - 18L/min. As shown in Fig. 3, specimens were prepared for the root-pass welding of V-groove butt joint with the dimension of 500×200×15.9mm. The groove angle, root-gap and root-face of the root-pass welding of V-groove butt joint were fixed 70°, 2.5mm and 1-1.5mm, respectively. The STT welding machine was excellently known to weld the V-groove base metal with the open-gap type and gone the stable root-pass weldment by controlled the heat input through the independent wire feed and the arc waveform control. Generally, the GMA welding process has been welded using the ceramic backing material inside the base metal to prevent the burn through, but the experiment for the study as the open-gap without using the backing material preformed. The Process parameter and level for vertical/overhead positions selected are shown in Table 1. The experimental design was developed to include selecting an experimental design, choosing process parameters and their limits, executing the experiment, and analyzing the differences of the back-bead geometry by the welding position, torch angle and welding speed depending on the same arc current (peak current: 397A and base current : 80A) and the wire feed rate (310CPM).

Table 1. Process parameter and level for vertical/overhead positions

Process parameter	Symbol	Unit	Level		
			-1	0	1
Torch angle	T_a	Degree	50	60	70
Welding speed	W_s	Cm/min	10	15	20

2.2. Experimental Results

Data collection and evaluation has been carried out using the robot welding facility. To measure the back-bead geometry, the specimen was cut transversely from the middle position using a wire-cutting machine. In order to assure the precision of the specimen dimension, it was etched by 3% HNO3 and 97% H20 nital solution to display back-bead geometry. The metallurgical microscope interfaced with an image analysis system has been employed to measure the back-bead geometry and represented in Table 2.

As indicated in Figs. 4 and 5, it showed that the back-bead width was wider in the overhead position than the vertical position. The back-bead width is continuously increased depending on the welding speed increases, however decreased from 15cpm. The back-bead width is gradually decreased depending on 50° to 60° of the torch angle and increased from 60° to 70°. According to Figs. 6 and 7, it was confirmed that the back-bead height showed opposite trends depending on the welding positions, each independently of welding speed and torch angle.

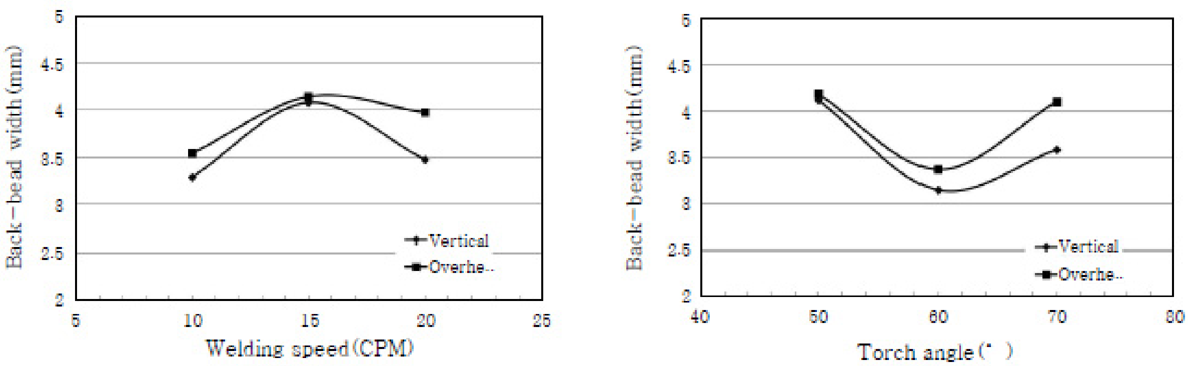

Fig. 4. Comparison of back-bead width with welding speed and torch angle

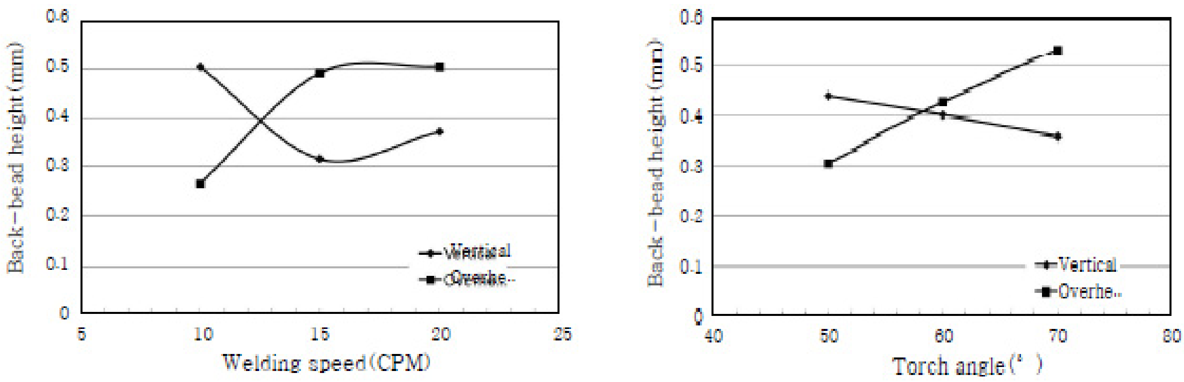

Fig. 5. Comparison of back-bead height with welding speed and torch angle

Table 2. Results of experiment

No/Position		Process parameter		Back-bead geometry	
		W_s	T_a	W_b	H_b
1	Vertical position	10	70	3.6	0.6
2		15	70	3.32	0.11
3		20	70	3.84	0.36
4		10	60	2.56	0.4
5		15	60	4.16	0.36
6		20	60	2.72	0.44
7		10	50	3.72	0.52
8		15	50	4.76	0.48
9		20	50	3.88	0.32
1	Overhead position	10	70	3.56	0.12
2		15	70	4.28	0.72
3		20	70	4.48	0.76
4		10	60	3.08	0.24
5		15	60	3.02	0.44
6		20	60	1.01	0.6
7		10	50	4	0.44
8		15	50	5.12	0.32
9		20	50	3.44	0.16

3. Results and Discussion

3.1. Development of the Empirical Model

Since the welding process consists of very complicated non-linear relations, it is very difficult to accurately predict the back-bead geometry in such welding process [8]. However, the approximate back-bead geometry may be predicted by the mathematical modeling. The experimental results were used to develop the empirical model to select the optimal welding condition from the given torch angles and welding speed. The development of empirical model may be achieved by combining process parameters on achieve the given back-bead geometry to select the optimal welding condition from the torch angles and the welding speed. The response variable (y) was expressed in the Eq. (1) below as the function in the back-bead width and the back-bead height with two welding parameters. The regression analysis was employed using the experimental results to develop the empirical model for the input and the output variables. The developed empirical model was expressed in the Eq. (2) and the coefficients of the developed empirical model were shown in Table 3.

$$y = f(T_a, W_s) \tag{1}$$

$$y = a_0 + a_1 T_a + a_2 W_s + a_3 T_a^2 + a_4 W_S^2 + a_5 T_a W_s \tag{2}$$

In which, y is the measured bed geometry, torch angle and welding speed. Also, are coefficients to be estimated for the model respectively.

Table 3. Estimated regression coefficients of empirical models

Constant	Vertical position		Overhead position	
	Back-bead width	Back-bead height	Back-bead width	Back-bead height
a_0	-16.8467	-9.2177	36.7511	-1.6888
a_1	-0.1640	0.2373	-0.8565	0.0873
a_2	1.1966	0.1433	-0.3216	0.0009
a_3	0.0036	-0.0011	0.0053	-0.0001
a_4	-0.0104	-0.0017	0.0009	0.0005
a_5	-0.0057	-0.0019	0.0040	-0.0011

Table 4. Variance test for developed empirical models

Developed empirical models		SSE	R-square
Vertical position	$W_{b\text{-}vert}$	0.548	0.901
	$H_{b\text{-}vert}$	0.046	0.864
Overhead position	$W_{b\text{-}over}$	3.620	0.882
	$H_{b\text{-}over}$	0.020	0.931

Taking into account the optimal welding conditions for underhead position as the basic welding condition, the empirical models for the vertical and the overhead positions was developed by selecting the torch angle (Ta) and the welding speed (Ws) as the input variables. The determination coefficient (R2) and the square sum of the residual (SSE) of the ANOVA were employed to verify the significance in the developed empirical models [7]. Table 4 shows the determination coefficient (R2) and the square sum of the residual (SSE) of the developed empirical models. To assess the accuracy in the developed models, the values calculated by the developed models were compared and analyzed for the measured values as shown in Figs. 6 and 7.

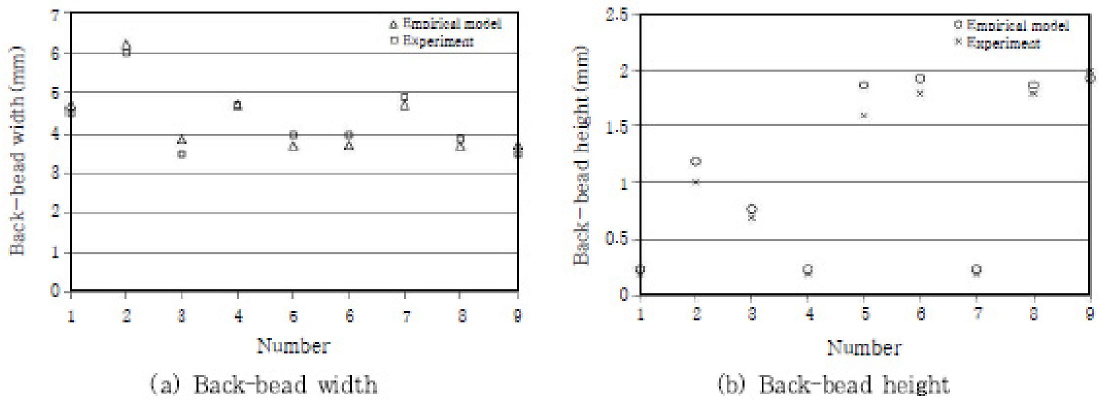

Fig. 6. Accuracy analysis for vertical position

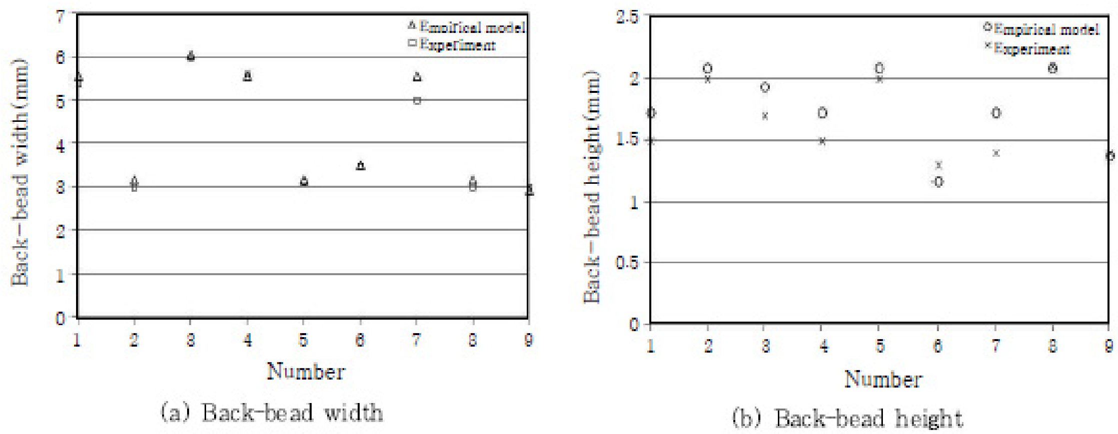

Fig. 7. Accuracy analysis for overhead position

It showed that the developed models for vertical position accurately predicted the back-bead width, but the prediction performance of the back-bead height decreased in some cases. For the overhead position, the poor prediction performance in the back-bead height was observed compared to the back-bead width, while the prediction performance was excellent as a whole. This means that not only the chosen welding parameters (torch angle and welding speed), but also other parameters which not included for this experiment affected the back-bead height. It is required to have in-depth consideration on the back-bead height. It is also concluded that the analysis of the main and interaction effects shall be required to investigate how each welding parameter affects the output parameters (back-bead width, back-bead height) as welding quality.

3.2. Interaction Analysis

The interaction analysis with the factors was investigated the effects of the torch angle and welding speed on the back-bead geometry. Figs. 8 and 9 indicated the interaction plots using the MINITAB, commercial statistics software. It can be showed that the back-bead width in the vertical position was largely affected by the changes in the torch angle with 15cpm of the welding speed. The interaction effect with the torch angle was low at 10cpm and 20cpm of the welding speed and not clear found. Similarly, the back-bead height showed very large interaction effects with the torch angle at 15cpm of welding speed.

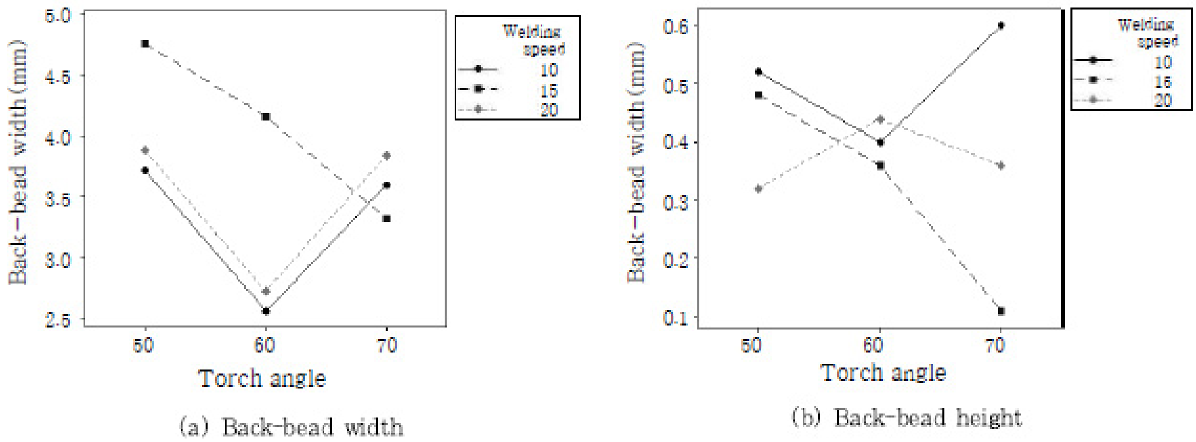

Fig. 8. Interaction effects for vertical position

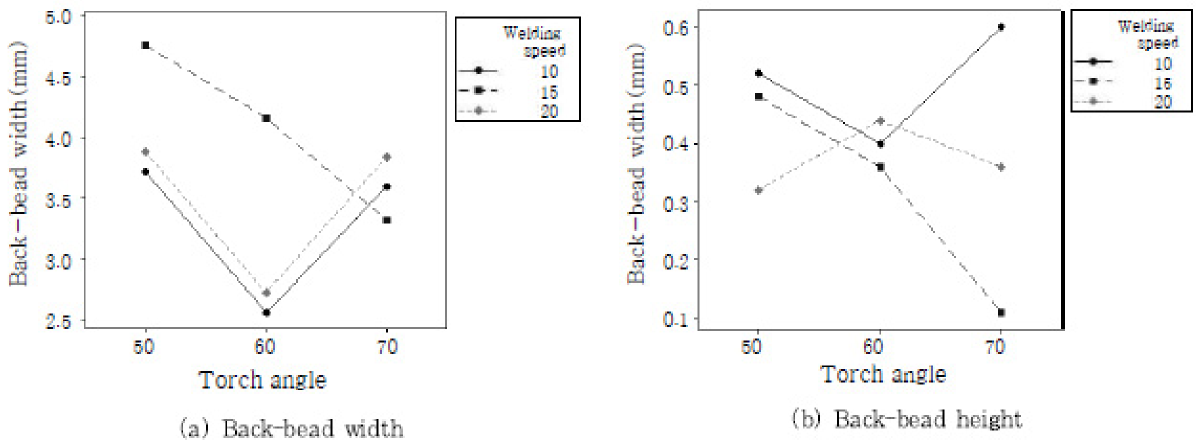

Fig. 9. Interaction effects for overhead position

For the overhead position, the interaction effects with the bead-bead width and the bead-bead height was the most outstanding at 15cpm and 20cpm of the welding speed. However, it can be presented that the interaction effect was found at 10cpm, but only interaction analysis could be difficult to control the bed geometry included back-bead width and the back-bead height. Therefore, it could be concluded that variation of the torch angle by fixing 15cpm of the welding speed is effective to control the back-bead width and back-bead height as welding quality.

4. Conclusions

The welding experiment has been carried out to select optimal welding condition in root-pass welding of V-groove butt joint for the pipe and the conclusion is as follows.

1) According to experimental results, the back-bead width was wider in the overhead position than the vertical position. The back-bead width is continuously increased depending on the welding speed increases. However, the back-bead height showed opposite trends depending on the welding positions, each independently of welding speed and torch angle
2) The empirical models has been developed to study the effects of welding parameters (torch angle and welding speed) on the back-bead geometry and to predict the optimal welding parameters with the open-gap type using the STT welding machine for the root pass welding for all the positions in the pipeline. the analysis of the main and interaction effects shall be required to investigate how each welding parameter affects the output parameters (back-bead width, back-bead height).
3) The interaction has been carried out to investigate the effects of the torch angle and the welding speed on the back-bead geometry(back-bead width and back-bead height) in the vertical and the overhead positions which applied for the pipeline. The variation of the torch angle by fixing 15cpm of the welding speed is effective to control the back-bead width and back-bead height as welding quality

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References

[1] S. B. Jones, Process Tolerance in Submerged Arc Welding, Weld. Inst. Research Report 1, 1976.
[2] W. S. Kim, Y. P. Kim, C. M. Kim and J. H. Baek, Comparison for grth auto welding procedure of field construction of gas pipeline, Journal of KWS, 21-3, pp.105-108, 2003.
[3] W. S. Chang, M. Y. Lee, and B. Y. Yoon, High current keyhole GTAW for stainless Steels and ti alloys, Journal of KWS, 22-6, pp. 6-9, 2004.
[4] R. S. Ha, B. H. Jung, and H. S. Park, Structure and defects in welds of high strengths al alloys by using GTAW,. Journal of KWS, 21-5, pp.540- 546, 2003.
[5] R. S. Chandel, Mathematical Modeling of Gas Metal Arc Weld Features, Proceedings of the Fourth International Conference on Modeling of Casting and Welding Processes, pp.109-120, 1988.
[6] T. Shinoda and J. Doherty, The Relationships Between Arc Welding Parameters and Weld Bead Geometry, The Welding Institute Report 74, 1978.
[7] D.C. Kim and S. H. Rhee, Design of an Optimal Fuzzy Logic Controller Using Response Surface Methodology, IEEE Trans on Fuzzy systems 9-3, pp.404-412, 2001.
[8] H. S. Park, T. H. Kim, and S. H. Rhee, Optimization of Welding Parameters for Resistance Spot Welding of TRIP Steel Using Response Surface Methodology, Journal of KWS 21-2 pp. 76-81, 2003.
[9] J. Y. Lee, J. W. Kim, and C. H. Kim, A study on the selection of fillet weld conditions by considering the tack welds, Journal of KWS 24-5, pp.377-384, 2006.